

# Opportunity for an Interdivisional Astrophysics Initiative at Argonne

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## Abstract

Representatives from the Materials Science, Physics, and High Energy Physics divisions have discussed possible new initiatives in astrophysics, and have outlined the general principles upon which they should be based. Science interests have been identified which are shared by the three divisions. These common themes are described, as well as details of the current programs in each division. The most promising science theme that combines interdivisional interest, current expertise and facilities at Argonne, and possibilities for expansion is supernova science and its connections to dark energy measurements. Potential future experiments are also briefly reviewed, and a generic detector R&D program is discussed.

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## Executive Summary

Interest in astrophysics continues to grow in the general public, scientific community, and at Argonne. A committee of representatives from the Materials Science, Physics, and High Energy Physics divisions has discussed possible new programs in astrophysics, explicitly looking for a joint project that would be the basis for a lab-wide initiative. We have reviewed the current program in each division, discussed common areas of scientific interest, and surveyed possible experimental projects.

The most promising science theme that combines expertise and facilities at Argonne, common interests in each division, possibilities for growth, and national scientific priority, is supernova science and its connections to dark energy measurements. This initiative would address two of the eleven Grand Challenges in physics and astronomy identified by the National Academy of Science's "Turner Report": 1) the completely unknown nature of the dark energy which constitutes 70% of the universe, and 2) the origin of elements from iron to uranium, a subject with considerable effort and expertise currently at Argonne. These topics are intimately linked by experimental measurements and theoretical modeling of supernovae. Type Ia supernovae provided the initial discovery of dark energy in 1998, and are still the most mature technique in the study of its properties. Synthesis of half the nuclei heavier than iron is expected to occur in supernova explosions. Moreover, supernovae are interesting objects on their own and are the subject of additional science priorities at the funding agencies.

Multiple types of supernova will be used in dark energy studies, including Type Ia supernovae (detonations of white dwarfs) and gamma-ray bursts (a subset of core-collapse supernovae). On the experimental side this initiative would likely provide expertise in the techniques used to observe Type Ia supernovae and constrain dark energy with them. Expertise in gamma-ray bursts (GRBs) already exists in the HEP division with the recent hire of named-fellow Deirdre Horan, and the detection of GRBs is a priority of the VERITAS experiment. HEP is working on upgrades for VERITAS that will lower the gamma-ray energy threshold, thereby improving GRB detection.

Observations and models of supernovae will require tremendous refinement before they produce the desired constraints on dark energy. Theorists hired by this initiative, working with Jim Truran and Ken Nollett from PHY, and with scientists at the Flash Center, would work on the nuclear physics and astrophysics of supernovae. They would provide close coupling to theory for measurements made in all three divisions.

Existing facilities and expertise in PHY and MSD provide critical measurements for supernova models, and would also be greatly enhanced by new hires seeded by this initiative. Measurements of helium-burning rates are a top DOE nuclear astrophysics goal, and are vital for understanding supernovae. Measurements of pre-solar grains probe nucleosynthesis in supernovae, and the search for  $^{244}\text{Pu}$  in deep-sea sediments will indicate whether *r*-process nucleosynthesis occurs in supernovae. Looking ahead, the committee sees a need for a longer period of study to determine what experimental opportunities are open to Argonne before a large investment in a single project is made.

Argonne has an opportunity to become a unique center for supernova studies, combining astrophysical measurements, theoretical studies, and accelerator and specialized-detector measurements to constrain supernova models and the evolution of dark energy.

## Introduction

Astrophysics is going through an exciting period. Astronomical observations, covering the full spectrum of wavelengths, have revealed new and unexpected results that will fundamentally influence our understanding of Nature. On Earth we have started to simulate some of these processes in the laboratory and together with improved computational capabilities considerable advances have been made in understanding the events observed in the cosmos. The many facets involved in such an analysis have led to a multi-pronged approach, which can best be pursued at a multi-purpose National Laboratory like Argonne. This is demonstrated by the wide spectrum of astrophysics theory and experiments studied at various Argonne divisions. Although small steps of combining the efforts of different groups have been made in the past, a lab-wide interdivisional astrophysics initiative would give a critical boost to this all-important field.

One way to expand astrophysics at Argonne is to choose a circumscribed area of astrophysics and seek to build a world-leading effort in that area. To be effective, such a choice should build on existing expertise at the laboratory, both in the form of scientific knowledge of the field and in the form of expertise in relevant experimental techniques. This will reduce the amount of new resources needed and get the effort off to a faster and more visible start. It will also make the recruiting of new talent easier because new recruits will see an ongoing effort where they can find collaborators, expertise, and intellectual stimulation.

We list below science topics that the committee has identified as areas in which there is ongoing effort spanning multiple divisions. For each of these areas, one can envision a similar approach to building an initiative. The important problems for any multi-divisional effort are; 1) identifying local strengths, 2) building depth of science knowledge in staff not presently trained as experts in astrophysics, 3) ensuring synergy between the divisional efforts by choosing an area in which fruitful cooperation is possible and by ensuring that there are many opportunities for interaction. A “generic” approach, once a science topic has been chosen, might look like this:

1. Host a visitor program, possibly consisting of a series of focused workshops, to bring in outside experts. This will advertise the local expertise, build collaborations with outside scientists, and provide opportunities to identify areas where Argonne's unique capabilities can make important contributions. A focused effort to invite seminar speakers who will interact closely with the local staff would also be useful, for similar reasons.
2. Hire young scientists whose training spans both areas of existing local interest and more specialized astrophysical knowledge. These could be postdoctoral or staff appointments, or a mix of the two. A few sufficiently broad-minded young scientists, preferably a mix of experimentalists and theorists, would likely form an effective “glue” to ensure synergy among the divisional efforts.

3. Build on the significant astrophysics efforts at other local institutions to attract talent and seminar speakers, and keep an eye open for opportunities to collaborate with them.
4. Identify and invest in experimental efforts that will make Argonne a leader in the chosen area.
5. Expand the existing astrophysics lunch seminar into a more frequent, and funded, forum in which the groups in different divisions, and in particular their younger members, come together and discuss science.

The following four sections describe areas of related research interest across multiple divisions. These vary in degree of present participation of each division and in the prospect for experiments where Argonne can have a large impact. It is the sense of the committee that the strongest of these areas, both for the present effort and for future expansion of astrophysics at Argonne, is supernova science, including its role in dark energy constraints. Only for this case have we included the outline of a plan for the future. (Similar outlines for the other science areas are deferred to Appendix 4.) However, even this area lacks a single project on which there is a clear case for collaboration across divisions. In the near term, a supernova initiative would most likely concentrate on expanding present efforts and looking for opportunities to contribute to a supernova survey oriented toward constraining dark energy. Work remains, beyond the timescale of this committee, to find a major experiment that we can either join or help establish.

Excellent opportunities exist for long-term funding of a dark energy/supernova group based at Argonne. DOE HEP has recently presented a list of experiments with CD-0 approval, this includes one for a generic ground-based dark energy experiment. The budget for dark energy studies is one of the fastest growing in DOE HEP. Moreover, in a report commissioned jointly by NASA, DOE and NSF, Connecting Quarks with the Cosmos, the National Academy of Sciences identified dark energy as one of the eleven Grand Challenges for physics and astronomy for which the prospect of a breakthrough in the next decade was high. Within this area, understanding standard candles (and supernovae in general) builds on an Argonne/UC strength, directly improves the scientific output of ongoing DOE Dark Energy studies, and in its on right directly impacts a second of the grand challenge outlined this report – the origin of the elements from iron to uranium. We hope that funding here will help Argonne to begin interaction with the Dark Energy community allowing identification of broader and more direct opportunities for interaction. The effort proposed here would attempt to build those bridges. These facts, coupled with the unique facilities and scientific expertise that Argonne can provide, bode well for future base funding of such a proposal.

## Dark Energy and Supernovae

The discovery of dark energy in 1998 was universally hailed as the science breakthrough of the year, and one of the most important science topics to be addressed in the 21<sup>st</sup> century. This discovery was made by measuring the brightness of Type Ia supernovae as a function of redshift, and their absolute brightness were corrected with a simple one-parameter function of the width of their light curve. Spectrum and

polarization data have shown that Type Ia supernova are more complicated than this, and they must be better understood before precise measurements of dark energy and its evolution can be performed. In addition, long duration gamma-ray bursts are a particular type of supernova, and are just beginning to be used in dark energy measurements. They will also have to be better understood in order to precisely constrain dark energy. Other proposed ways to constrain dark energy, such as weak lensing, are also relatively new and have unknown systematic effects at this time.

Supernovae and their products are prominent topics of research in astrophysics, linking many different types of science. First, there is the problem of explosion mechanisms. It is presently thought to be well-established that supernovae of Type Ia are produced by thermonuclear detonation of white dwarfs, while supernovae of Types Ib, Ic, and II, as well as long gamma-ray bursts, are produced by core collapse of massive stars. While these mechanisms are well-established by empirical observations of energetics, spectral lines, remnants, etc., the details of the mechanisms are very complicated, and theorists are still trying to produce complete end-to-end theoretical models of the explosion mechanisms. Indeed, theoretical understanding of these mechanisms is the focus of DOE nuclear astrophysics milestones for years 2009 and 2013.

However the energy is produced, its release triggers nuclear reactions in the progenitor and provides the mechanical energy to expel nucleosynthetic products into the interstellar and intergalactic media. The explosion leaves behind remnants, consisting at least of expelled material expanding outward, and in the case of core collapse, an additional compact remnant that is either a neutron star or a black hole. If the neutron star is a pulsar, it is eventually observable in many wave bands, from radio to TeV gamma-ray. The dispersed material is observable in a similarly wide range of wavelengths, ranging from radio to optical to X-ray, where its structure and composition yield information about the progenitor and explosion, to MeV gamma ray lines from decays of nucleosynthetic products. At late times, as the remnant plows into the interstellar medium (ISM), the resulting shell of plowed-up material produces X-rays and TeV gamma rays, and is a likely source of the Galactic cosmic rays.

It was found in the 1990's that Type Ia supernovae can be used as "standard candles," the intrinsic brightness of which can be inferred from other observational quantities and used to determine the relation between redshift and luminosity distance. Considerable effort not just from the astronomy community, but also the particle physics community is now going into supernova surveys to constrain dark energy. Questions about many factors affecting intrinsic brightness, such as the carbon-to-oxygen ratio in the progenitor white dwarf, are being revisited. The supernova progenitor and explosion have to be better understood before critical measurements such as the time evolution of dark energy can be performed.

Argonne has existing efforts aimed at several aspects of supernovae, and these form a natural base from which to begin building expertise and to build our visibility to the world as a center for supernova science. The Physics Division theory group has strong ties, through a joint staff appointment, to the effort to understand thermonuclear supernova explosions at the University of Chicago Flash Center, and particularly to efforts to compute nucleosynthesis in the burned material. This effort is the subject of a DOE nuclear astrophysics milestone for year 2009. A closely-related matter under experimental investigation in Physics Division is the low-energy suppression of fusion

reactions, which might affect the conditions for initiation of the explosion by the  $^{12}\text{C}+^{12}\text{C}$  reaction. For core-collapse supernovae, members of both Physics and HEP divisions have been involved in discussions of a supernova neutrino detection experiment, known as ADONIS.

In both types of supernovae, both charged-particle and neutron-induced reaction rates are important for the nucleosynthesis; the low-energy experimental effort in Physics Division is oriented toward providing such rates, which are the subject of the DOE nuclear astrophysics milestone for year 2012. A particularly successful example is the effort during the last few years to constrain the production of the radioactive nuclide  $^{44}\text{Ti}$ . Efforts of this kind connect not just to gamma-ray lines potentially or actually observable in supernova remnants ( $^{44}\text{Ti}$ ,  $^{26}\text{Al}$ ,  $^{60}\text{Fe}$ ...), but also to optical and X-ray observations constraining the nucleosynthetic outputs of supernovae. They also link to pre-solar grains, some of which formed in supernovae and contain the best if not only source of information on isotopic composition of newly-synthesized material. Presolar grains are in turn the focus of a large amount of effort in Materials Science Division, which leads the world in measuring isotopic compositions of trace elements in such small samples.

After most of the nucleosynthesis has taken place, the event becomes visible to observers. Some portion of core collapse supernovae in very massive stars become gamma-ray bursts (GRBs). It is not yet known whether the signal in these events produces photon energies in the TeV range, but the VERITAS collaboration, which includes members from HEP division, is actively searching for such a signal.

As the ejected material continues to expand outward for several thousand years before finally mixing with the general ISM, it plows up large amounts of the surrounding ISM at a shock. Such shocks are thought to be the main acceleration site for Galactic cosmic rays. A major target of study for gamma-ray telescopes like VERITAS is the TeV gamma-ray emission from these shocks. In addition to enabling study of the remnants themselves (complementary to X-ray observations), the energy spectra observed by VERITAS will shed light on the role of supernova remnants in Galactic cosmic ray acceleration: acceleration of hadrons should be accompanied by  $\pi^0$  production, so a spectrum characteristic of  $\pi^0$  decay would be strong evidence that supernova shells are the main acceleration site for cosmic ray nuclei. The recently-appointed named fellow in HEP, Deirdre Horan, is a GRB expert and is currently PI on a GRB proposal to see the higher energy component of the burst. GRBs have been proposed as an alternative standard candle to Type Ia supernovae, since there is a good correlation between peak brightness and total measured energy output. They are also observed at much higher redshift than Type Ia supernovae, making them a candidate for measurements of the time evolution of dark energy. This effort would be a natural addition to the supernovae plus dark energy program discussed above.

Work at RIA will make important contributions to understanding of the *r*-process (which most likely occurs in supernovae) by providing information about nuclei on the neutron-rich side of the valley of stability. If the *r*-process occurs in the neutrino-driven winds of supernovae, reactions of light nuclei are important for producing the seed nuclei and setting the neutron-to-seed-nucleus ratio; local theoretical expertise in reactions of light nuclei should reduce the uncertainties on the rates of these reactions, especially in neutron-rich light nuclei. Materials Science Division is also working on methods to search for  $^{244}\text{Pu}$ , a short-lived *r*-process product, in deep-ocean sediments. Its presence

there would provide a link to a supernova site by connection with already-claimed detections of  $^{60}\text{Fe}$ . We note that the  $r$ -process is also the focus of the DOE nuclear astrophysics milestones for years 2007 and 2012.

Applying the “generic” framework above, an interdivisional initiative building on this effort might look like the following:

1. Host a series of workshops in one or more of the following areas: 1) supernova nucleosynthesis, 2) supernova and gamma-ray burst constraints on dark energy, 3) the role of supernovae in the Galaxy (nucleosynthesis, cosmic-ray acceleration, heating of the ISM, dust lifetimes...), 4) supernova remnants, 5) “interim” science for ADONIS to do while waiting for a Galactic supernova.
2. Hire a staff theorist trained in hydrodynamical aspects of nuclear astrophysics (presumably fitting best into Physics Division), with money for a postdoc; hire a theory postdoc in HEP trained in dark energy.
3. We have good existing ties to supernova efforts at the University of Chicago through the joint appointment of Truran; we can expand on this connection by making sure that there is contact between Argonne people and relevant visitors to the university.
4. Expand the experimental astrophysics efforts in all three divisions with postdoc appointments. One example of this would be a postdoc in Materials Science to work on the search for  $^{244}\text{Pu}$  mentioned above. Astrophysics experiments to invest in will have to be determined as we go along, and our ability to identify these areas will depend crucially on what sorts of people we bring in both on the payroll and as visitors. It also depends on external factors such as the Dark Energy Task Force report which is not yet public. New postdocs in HEP could support participation in the gathering and use of very large samples of supernovae produced in dark energy surveys (like DES and LSST), and this could be coupled to an expanded supernova effort in Physics Division. ADONIS could become a flagship experiment supplying a clear set of goals, provided that short-term science goals can be identified for the period between construction and the next nearby supernova. VERITAS and its successor instruments also link to supernovae via efforts to observe gamma-ray bursts and via the study of supernova remnants. Increased local focus on supernova problems would likely lead rather naturally to identifying related experiments that Physics Division is well-placed to carry out. Argonne could also buy into the ATLAS large-telescope project -- assuming that the proposal goes forward -- though this will only bring science participation if we can find a reasonable location for optical astronomers in the laboratory. Given a solution to the problem of how to hire an astronomer (and given a spectrometer on the telescope), buy-in on ATLAS could be coupled with the hiring of an astronomer or astronomers who will use it to study supernovae, perhaps doing spectroscopic follow-up on supernova samples gathered in the dark-energy surveys (a major gap at present in use of those samples).
5. In addition to the astrophysics seminar, institute a regular “supernova science” seminar or discussion group as a way of binding the various efforts, ensuring that



opportunities are recognized and producing good science from all connected groups.

## Nucleosynthesis and Cosmochemistry

The big bang produced only hydrogen, helium, and lithium in measurable quantities. The chemical (or more precisely, nuclear) composition of the universe around us was determined not only by this initial event but also by subsequent cycles of star formation, nucleosynthesis, and return of processed material to the ISM. The observable outcomes of this process were until recently just the solar system composition (the only sample for which extensive information about *isotopic* composition was available) and the elemental compositions of individual stars and nebulae subjected to spectroscopic study. Two major new sources of information have arrived in the last fifteen years: presolar grains recovered from meteorites, with isotopic compositions reflecting specific nucleosynthetic environments, and the advent of large automated sky surveys, which are beginning to produce quantities of data on metal-poor stars sufficient to do serious statistical studies of their chemical compositions. Two recent NASA sample-return missions are also important to this area: the Genesis mission that brought back samples of the solar wind -- an important source of information about the isotopic composition of the solar system -- and the Stardust mission that brought back samples of both comet dust and contemporary interstellar dust.

Argonne has one of the world's premier facilities for the study of presolar grains, in the CHARISMA and SARISA instruments in the Materials Science Division. These instruments are also primary facilities for studying materials from the sample-return missions. Argonne and the larger collaboration forming the Chicago Center for Cosmochemistry constitute a leading center for this type of research. The MSD group has shown that many of the presolar silicon carbide grains have heavy-element compositions that can be explained extremely well by the *s*-process in AGB stars. A subset of presolar grains known to originate in supernovae explosions has also been studied in detail by the MSD group. In Physics Division, there has been related theoretical work to determine what portion of the carbon, nitrogen, oxygen, and aluminum isotopic compositions of presolar grains, as well as the short-lived radionuclide inventory in the early solar system, can be explained by synthesis in AGB stars.

All meteorites are believed to have been broken off of larger asteroidal parent bodies. Cosmic-ray bombardment of a meteorite produces krypton nuclei, which were not present in the rock when it condensed. The abundance ratio of unstable  $^{81}\text{Kr}$  to stable  $^{83}\text{Kr}$  gives the cosmic-ray exposure time of the meteorite. Since cosmic rays cannot penetrate deep into an asteroid, the cosmic-ray exposure time of a meteorite is the amount of time since separation from its parent body. Work is beginning in Physics Division to extend atom trap trace analysis to measurements of  $^{81}\text{Kr}/^{83}\text{Kr}$  in meteorites.

Turning to large-scale automated star surveys, getting the best scientific returns from these efforts will require an increase in sophistication of models of Galactic Chemical evolution. The Physics Division theory group is home to expertise in such models and will be involved in their elaboration.

As mentioned above, cosmic-ray source compositions are in principle

sources of information about ongoing nucleosynthesis. VERITAS will contribute to the resolution of the question of what the sources of the nuclei are.

A necessary underpinning of all of this activity is the ability to compute models of nucleosynthesis. This involves not only theoretical expertise for modeling nucleosynthetic environments – something well-represented locally in modeling big-bang nucleosynthesis, AGB stars, Type Ia supernovae, novae, and the *r*-process -- but also empirically-based nuclear properties that are vital inputs to the calculations.

The Physics Division is a leader in experimental nuclear astrophysics, with a track record of measurements relevant to many different nucleosynthetic environments. This sort of work underpins all of nuclear astrophysics and nucleosynthesis, as evidenced by aspects of it in the DOE nuclear astrophysics milestones for years 2007, 2009, 2010, 2011, and 2012.

## Compact Objects

Another very active area of research is in compact astrophysical objects. These are white dwarfs, neutron stars, and black holes. Neutron stars and black holes in binary systems, in particular, are the focus of a great deal of effort in X-ray astronomy. Some of these neutron stars accrete hydrogen- and helium-rich material from the envelopes of their companion stars. The accreting material forms an accretion disk that heats up from the released gravitational energy and shines brightly in X-rays. As accreting material accumulates on the surface of the neutron star, it is compacted and heated, and periodically flares up in an X-ray burst, a brief period of nuclear burning in which the accreted hydrogen and helium form heavier elements with tremendous release of energy. The main observable quantities in such an event are its luminosity and the evolution of luminosity with time.

An analogous but somewhat less dramatic event occurs in binary systems containing a white dwarf instead of a neutron star. In these systems, there is less gravitational energy release and densities do not reach as high, but the accreted material does eventually reach conditions for thermonuclear runaway. The resulting event produces a brief spike of luminosity reaching into the UV, followed by a few months of cool-down observable at visible and infrared wavelengths. In addition to producing a transient astronomical signal, novae synthesize nuclei that escape and might make a noticeable amount of the Galaxy's inventory of some nuclei like  $^{13}\text{C}$  and  $^{15}\text{N}$  that are difficult to make elsewhere. Until recently, a class of presolar grains recovered from meteorites was attributed to novae. It is thought that some accreting white dwarf systems eventually become the progenitors of Type Ia supernovae.

A great deal of experimental work in the Physics Division has focused on reaction rates and nuclear masses that are needed for the X-ray burst and nova problems. This work has been motivated by the combination of accessibility of relevant nuclear systems in the laboratory and theoretical calculations showing that nuclear properties can make a big difference in the observed outbursts. Many of the local measurements relate to the prospect of breakout from the hot CNO cycle to hydrogen- and helium-burning on heavier nuclei in novae; the mass measurements involve larger nuclei, like  $^{68}\text{Se}$  and  $^{64}\text{Ge}$ , that are relevant to the X-ray burst problem. In addition, Truran and his students and

postdocs (all with appointments at the University of Chicago) are extensively involved in calculations of nova outbursts, evolution of white dwarf binary systems, and the thermal states of accreting neutron star crusts. These experimental and theoretical efforts support a 2009 DOE nuclear astrophysics milestone. The Physics Division has extensive connections outside the lab in this area, and has in the past organized a workshop on X-ray bursts.

The Physics Division has recently been home to work on neutron star cooling and the properties of quark stars that result if quark matter is stable. This has produced in particular important work on the differences in observable properties between quark stars and “normal” neutron stars. The Physics Division has also been instrumental in producing nucleon-nucleon interactions used to determine the equation of state of neutron stars. These areas are the subject of the 2013 DOE nuclear astrophysics milestone.

The VERITAS experiment will see compact objects within the Galaxy. The Crab Nebula pulsar was the first object to be observed in high-energy gamma rays, and it has become a unit of flux because it is the easiest object in the sky to observe. VERITAS will most likely observe many similar objects. It will measure their photon spectra at the highest energies, and will discover many new objects. Some of these are likely to represent completely new classes of compact objects.

## Cosmic Rays

Cosmic rays are mostly very high-energy nuclei in our own Galaxy, arriving from all directions with a spectrum that follows a sharply-declining power law with respect to energy. Despite the steep fall-off, the spectrum spans many orders of magnitude in particle energy. The source of the Galactic cosmic rays and the relative abundances of nuclei at the source remain unknown, though plausible ion sources and acceleration sites, such as the supernova site mentioned above, are known. Detailed measurements of cosmic-ray composition are only possible on space- or balloon-borne instruments, though compositional information can also be obtained from ground-based measurements of air showers.

The Pierre Auger Observatory, being built in Argentina with participation from the HEP Division, is designed to examine cosmic rays around  $10^{18}$  to  $10^{20}$  eV, where the Greisen-Zatsepin-Kuzmin (GZK) cutoff should bring an end to the spectrum, and where the Galaxy loses the ability to confine protons.

Measurement of the spectrum will test the presence of the GZK cutoff and examine the range of energies where the particle source may be changing because of Larmor radii comparable to the size of the Galaxy. The Auger Observatory combines an air shower array with air fluorescence telescopes and will provide enough events to do useful statistics in the crucial energy range to see whether the GZK cutoff is present. The simultaneous use of the two detection techniques will provide a sample of highly-constrained air shower events and will allow a cross-calibration of the techniques. In the last year, Argonne has been an important site for measurements of the fluorescence yields that are needed to make use of the air fluorescence signal.

Propagation of such high-energy particles through the cosmic photon background also produces pions that decay to produce very energetic neutrinos. The Auger Observatory should be able to observe some events triggered by such neutrinos, seen as showers with large zenith angle that start many proton interaction-lengths into the atmosphere. HEP Division is also involved in efforts to develop radar detection of such showers.

Auger will also provide composition data, so that it can be determined whether the cosmic-ray primaries in the  $10^{18}$  to  $10^{20}$  eV range are mostly protons or mostly heavier nuclei. If there are events beyond the GZK cutoff, or a switch from Galactic to extragalactic sources, or a switch to some new source within the Galaxy, this will shed light on their provenance.

In a less exotic regime, the much more numerous cosmic rays of lower energy carry in their composition clues as to their places of origin. This will ultimately connect back to nucleosynthesis, although the problem is presently entangled in questions of the ion source, acceleration mechanism, and nuclear interactions with the ISM. As mentioned in the supernova section, VERITAS will help determine the viability of supernova shells as sites of cosmic-ray acceleration by measuring the spectrum of TeV gamma-rays coming from the shells.

Cosmic rays can also be important in cosmochemistry. Cosmic rays impinging on the solar nebula or its precursor molecular cloud are credible sources of some radioactive nuclei that were present in the early solar system, and this connects to efforts in the Chicago Center for Cosmochemistry and in Materials Science Division.

Finally, not all air showers are produced by nuclei. The VERITAS collaboration is building a large Cherenkov telescope to observe gamma rays in the TeV range. In addition to providing constraints on the acceleration sites of the cosmic-ray nuclei, the present generation of Cherenkov telescopes will do a large amount of astronomy with these photons. This includes study of the Galaxy, compact objects, the cosmic photon background, dark matter, and gamma-ray bursts. Since the opening up of new wavebands has in the past always revealed new types of objects, it is rather likely that completely new classes of objects will be found.

## **Appendix 1: Materials Science Division Overview**

The Materials Science Division has two facilities for the analysis of extraterrestrial matter: the CHARISMA (Chicago-Argonne Resonant Ionization Spectrometer for MicroAnalysis) and SARISA (Surface Analysis by Resonant Ionization of Sputtered Atoms) instruments. CHARISMA has been providing detailed analyses of presolar stardust grains since 1997, while SARISA is now providing ultra-trace analysis of solar wind samples returned by the Genesis mission. In addition, we are preparing to make measurements on cometary and interstellar dust samples collected by the STARDUST mission, and on supernova-produced Pu isotopes in deep-sea sediments.

The isotopic composition of heavy elements in individual stardust grains has been studied by Michael Pellin and Michael Savina and provides data on the nucleosynthesis conditions in stars. These analyses are challenging because; 1) the grains are very small, the largest being perhaps a few microns in diameter, 2) they contain only

trace (ppm) concentrations of heavy elements and 3) isobaric interferences must be strongly suppressed. The CHARISMA instrument uses a microfocus laser to resolve individual grains, and tunable lasers to discriminate the element of interest from the other elements present in the grains. These studies have provided highly detailed analyses of the isotopic record preserved in grains, which are used to verify and constrain theories of stellar nucleosynthesis; among these are theories of explosive nucleosynthesis in supernovae. For overviews of the instrument and its impact on the study of presolar grains see Savina et al., *Geochim. et Cosmochim. Acta* **67**, 3215-3225 (2003), and Lugaro et al., *Astrophys. J.* **593**, 486-508 (2003).

Evidence of fresh ( $\sim 3$  Myr old) supernova ejecta has recently been found in the form of live  $^{60}\text{Fe}$  in deep-sea ferromanganese crusts. We are currently engaged in a search for a far less abundant radionuclide,  $^{244}\text{Pu}$ , in deep-sea sediments. The successful detection would not only confirm the origin of the detected  $^{60}\text{Fe}$ , but would provide strong evidence that supernovae are in fact the site of the  $r$ -process and would constrain theories of explosive nucleosynthesis in supernovae. This analysis is by far the most challenging of its kind ever attempted: we estimate that the sediment contains  $\sim 10^6$  atoms of  $^{244}\text{Pu}$  per kg. We are currently in the method-development stage.

The solar wind is believed to be representative of the original material in the protosolar nebula, and thus of the ISM at the time of the formation of the solar system. The NASA Genesis mission recently captured samples of the solar wind for laboratory study. SARISA is the only facility capable of the elemental and isotopic analysis of the heavy ( $> \text{Fe}$ ) elements, which are generally present in ultra-trace quantities (generally sub-parts-per-billion) in these samples. A group consisting of Pellin, Savina, Igor Veryovkin and Wallis Calaway have recently completed the first analysis of Genesis samples by measuring solar-wind Mg isotopes implanted in the collectors. These measurements are now being analyzed and compared to theory and other measurements.

The NASA STARDUST mission recently returned with dust grains from the tail of comet Wild-2, as well as interstellar dust grains streaming into the inner solar system from the ISM. The cometary grains are believed to be representative of the solid matter in the early solar system, i.e. the first condensates from the gas phase plus pristine solids (stardust and ISM grains) originally present in the protosolar nebula. The isotopic analysis of cometary material will be determined by Pellin, Savina and postdoctoral researcher Jonathan Levine, and will shed light on the initial composition and subsequent chemical processing of the material from which the solar system formed. The collected interstellar grains represent contemporary ISM solids, as opposed to presolar grains which are  $> 4.5 \times 10^9$  years old. They also present an opportunity to study pristine stardust free of the selection bias and parent-body alteration inherent in presolar stardust grains isolated from meteorites.

## Appendix 2: Physics Division Overview

The Physics Division consists of three groups: low-energy physics, medium-energy physics, and theoretical physics. Astrophysics in the division is pursued primarily in the low-energy and theory groups. The effort in low energy concentrates on measuring nuclear cross sections and lifetimes for astrophysics, with experiments performed

primarily on-site at the ATLAS facility. The medium-energy group has developed an atom-trapping technique (ATTA) that is being elaborated into a tool for trace analysis in cosmochemistry. In the theory group, methods developed locally to compute wave functions of light nuclei are now being generalized to predict cross sections for astrophysics. Other work in the theory group, particularly in collaboration with the University of Chicago, focuses on nucleosynthesis in diverse sites and the presence of nucleosynthetic products in the solar system.

The theory group is home to an existing, mostly LDRD-funded, astrophysics initiative. This began with the hire of Ken Nollett as staff member in FY03 (replacing a retirement in nuclear structure) and the initiative from lab management to bring in Truran half-time from the University of Chicago and to hire an astrophysics post-doc (currently, Jaikumar). Nollett's expertise is in light-nucleus reactions, big-bang nucleosynthesis, stellar evolution, and pre-solar grains. Since arrival at ARGONNE, his efforts have included further work on low-mass stars and early solar system composition, numerical methods for calculating supernova neutrino-nucleus interactions, and development of a cosmic-ray propagation code. 30% of Nollett's effort is dedicated to developing quantum Monte Carlo calculations of nuclei into a tool that can predict astrophysical cross sections (probably limited to mass-12 and below). Jaikumar is halfway through a two-year appointment. He studies neutron-star cooling and properties of quark stars. It is possible that another post-doc of similar expertise will be hired around the time of his departure. Truran is an established leader in nuclear astrophysics, and he is involved in a wide range of efforts in this area. He is astrophysics group leader of the Flash Center, and involved in work on the Type Ia supernova problem, novae, the r-process, metal-poor stars (essentially a fossil record of the first round of star formation), X-ray bursts, and the nuclear-abundance history of the Galaxy. The theory group is also home to "latent" expertise on neutron star structure, in the form of Wiringa's work on nuclear matter and past calculations of neutron star equations of state based on these methods. An updated version of those calculations is possible and desirable, but has taken a back seat to other projects. Lee and collaborators have produced photo-hadron rates on nucleons from Jefferson Lab data and are looking to apply them to cosmic-ray propagation and the resulting neutrinos. Esbensen has done work on inferring low-energy nuclear reaction data for astrophysics from "proxy" experiments.

The Low Energy group is home to a large effort to measure cross sections, masses, and half-lives of nuclei for use in astrophysics. This program is currently pursued by several staff members (principally Rehm and Savard), two post-docs, and three students, and most of the work is done locally at the ATLAS facility. The largest amount of work, led by Rehm, has gone into cross sections for explosive nuclear burning. Much of this work relates to novae (proton burning on white dwarfs) and X-ray bursts (proton burning on neutron stars). Several experiments have looked at alpha and proton reactions on O,F,Ne for input to nova calculations. Proton captures at somewhat higher mass, like  $^{56}\text{Ni}(p,\gamma)^{57}\text{Cu}$ , that influence energy production in X-ray bursts have also been studied, as well as reactions in the region of Ca and Ti, important for production of  $^{44}\text{Ti}$  in supernovae. The most recent work from this group is the determination of a critical resonance strength for the  $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$  reaction that constitutes the largest single uncertainty in stellar astrophysics, by studying the  $^{16}\text{N}$  decay spectrum. This group is also home to the Canadian Penning Trap (CPT) group, led by Savard. They have recently

used the CPT for mass measurements of nuclei that are potential waiting points in X-ray bursts, where proton burning produces a nucleus at the proton drip line that cannot capture more protons until it beta decays. The masses determine the beta decay lifetime and thus the length of time proton capture will be delayed. Masses are similarly important on the neutron-rich side of stability in the r-process, and trapping is also useful there.

Other recent efforts in the low energy group include:

- Measurement of the  $^8\text{B}$  neutrino spectrum for solar neutrino studies
- Re-examination of processes that could bypass triple-alpha burning in the first generation of stars
- Half-life measurements of nuclei important for nucleosynthesis and cosmochemistry:  $^{44}\text{Ti}$ ,  $^{60}\text{Fe}$ ,  $^{146}\text{Sm}$ ,  $^{182}\text{Hf}$
- $(n,\gamma)$  cross sections for the s-process in massive stars measured by AMS of activated samples
- the discovery of suppression in heavy-ion fusion that may have implications for carbon and oxygen burning
- building high-acceptance solenoidal spectrometer that will be useful for astrophysics

Nuclear astrophysics will be a major activity at the RIA facility. While the time until RIA is built remains uncertain, the Physics Division will concentrate research efforts in the near future on reactions of astrophysical interest with existing technologies. This will support the bid to build RIA at Argonne and will position the group to carry out related experiments at RIA once it is built.

Apart from electron-scattering experiments at Jefferson Lab that can contribute to cross sections for cosmic-ray proton propagation, all relevant activity of the medium-energy group is in the atom-trapping group led by Lu. They have developed the noble-gas counting technique called atom trap trace analysis (ATTA), and used it to measure abundances of the unstable  $^{81}\text{Kr}$  and  $^{85}\text{Kr}$  atoms in large environmental samples (for example, using cosmic-ray-produced  $^{81}\text{Kr}$  to trace water flow in an aquifer in Egypt). At present, the efficiency is low, so a very large sample size is required. Lu has a collaborative grant with Andrew Davis of the University of Chicago to develop ATTA into a form suitable for studies of meteorites or samples returned by spacecraft. Higher efficiencies are needed for the smaller sample size, and it is necessary to develop trapping out of solids and detection of stable isotopes. Initial application will be to the  $^{81,83}\text{Kr}$  system in meteorites, where the ratio of the two nuclides gives the cosmic-ray exposure time of the meteorite and thus the time since it split off from its parent body. One can envision further applications of sensitive noble-gas counting techniques in meteorites relating to solar-system formation and the nucleosynthesis that preceded it, particularly in xenon. Earlier work by this group using helium spectroscopy also yielded new limits on the abundance of helium-like strangelets in the atmosphere.

The Physics Division is a participant in an NSF Frontier Center called the Joint Institute for Nuclear Astrophysics (JINA), and was a key player in getting it established. JINA PI's are located at Michigan State, Notre Dame, and the University of Chicago.

The University of Chicago PI is Jim Truran. Rehm is the principle Argonne participant (apart from Truran) in JINA, and one experiment postdoc in PHY is funded by JINA; several people in PHY are official JINA participants.

## **Appendix 3: High Energy Physics Division Overview**

The High Energy Physics Division has several different efforts related to air shower detection. The VERITAS experiment will precisely measure gamma-ray showers from 50 GeV to 50 TeV, with the main HEP goal being the detection of gamma-rays from dark matter annihilations. As a test for a possible upgrade to VERITAS, a telescope is being built on the Argonne site in collaboration with UC and Utah, to be read out with multi-channel PMTs. Studies of a next generation gamma-ray telescope are underway, with Argonne leading the technology and cost group. Another major effort in the division is the Pierre Auger Observatory, measuring the highest energy cosmic rays above  $10^{20}$  eV and the highest energy neutrinos above  $10^{19}$  eV. The absolute calibration of the fluorescence yield, one of the most important goals for the experiment, is underway using three unique electron/photon accelerators at Argonne. Finally, in collaboration with Brookhaven, a novel new detection technique using radar is being investigated, with the possibility of a much less expensive neutrino detector.

The VERITAS experiment is an array of four telescopes which use very high energy gamma-rays (50 GeV to 50 TeV) to observe both galactic and extra-galactic sources with large photon statistics, and perform high quality spectrometric, temporal and morphological studies. The Argonne group is led by Byrum. The science program includes both fundamental physics and exotics such as indirect dark matter searches, quantum gravity and searches for primordial black holes as well as the study of the most extreme astrophysical processes in the universe such as shell-type supernova remnants, active galactic nuclei and gamma-ray bursts. In addition, the potential for VERITAS to observe something new is very large.

When a high energy gamma-ray (photon) interacts in Earth's atmosphere, it produces a narrow avalanche of lower-energy electrons, positrons (which are mostly moving faster than the speed of light in the upper atmosphere) and gamma-rays and emit Cerenkov light, an electromagnetic shock-wave analogous to the sonic boom emitted by a supersonic jet. This light can be detected as a faint blue flash of short duration (tens of nanoseconds) at ground level. Cerenkov gamma ray detectors use tessellated mirrors to image the Cerenkov radiation into a camera composed of an array of photo-multiplier tubes (PMTs). Although the Cerenkov light is also produced by cosmic ray showers, the light from gamma-ray showers can be discerned by its comparatively smooth shape, compact angular distribution, and geometric pattern.

Currently, VERITAS is building and commissioning a 4 telescope array in Arizona. The first two telescopes are completed and are taking data in stereo mode. The remaining two telescopes are to be completed by the end of 2006. The collaboration intends to submit an upgrade proposal in Sept 2007 to build three additional telescopes (the initial VERITAS proposal called for a 7 telescope array and was downsized to 4 telescopes for funding reasons). These upgraded telescopes would have increased performance beyond the current 4.



In addition, recently a core of US gamma-ray scientists have organized themselves to plan for an international very large next generation ground based gamma-ray project with a time scale of 2010. Argonne is a member of this group and we would plan to use the VERITAS upgrade as a testbed for R&D concepts which could be built for this next generation project.

It is a major goal for the next generation of telescopes to extend extragalactic observations beyond isolated nearby active galactic nuclei. Viewing objects farther away will require lower thresholds to see photons not attenuated by pair production. The ability to observe and identify dark matter annihilation will be greatly improved by greater angular resolution, so that anisotropies in the signal can be shown to follow the pattern on the sky of large-scale cosmological structure.

Using LDRD seed money jointly with the University of Chicago, we are building a small telescope on site at Argonne. For this telescope, we are building a prototype fast finely pixelated digital camera which will obtain an order of magnitude better angular resolution while lowering the energy threshold for detection of sources out to red shifts of order 1. The proposed pixelation will be achieved by using multi-channel photomultiplier tubes (MAPMTs) readout with custom integrated circuitry operating at speeds of 1 GHz, an order 10 faster than similar devices of today. The architecture of the custom integrated circuit will be based upon the Particle Flow Algorithm technique which was developed for high energy physics experiments. We are in the process of designing the ASIC specifications and have engaged the Fermilab ASIC group to develop this chip for us. We currently have enough funding for the first iteration of a chip submission.

In parallel, we have also built a data acquisition system using pre-prototype electronics developed for the Main Injector Neutrino Oscillation Experiment (MINOS). This allows us to continue R&D of the camera independent of the development of the ASIC. One of the technological challenges of this project is to determine if multi-anode photo-multiplier tubes (MAPMTs) can be used in a telescope environment. The key question for this determination is whether MAPMTs have the sensitivity to measure signals of 3-100 photo-electrons in a shower in the presence of the high rates of photons from the night sky background. After studying several multi-pixel tubes, we have purchased 20 Hamamatsu R8900 16-channel PMTs and are currently assembling a camera which will initially consist of 4 tubes and expanded to 16. This initial camera will be readout with the MINOS electronics. We expect first results sometime this spring.

In addition to the above R&D, we have recently just started collaborating with the University of Iowa to develop a fast topological array trigger. The topological array trigger requires unique patterns in multiple telescopes located approximately 100 meters apart. The challenge in this trigger design is that it must operate at speeds greater than or equal to 500MHz. If successful, this type of trigger design would be important both for the VERITAS-7 upgrade as well as for a future next-generation large array.

The goal of the Pierre Auger Observatory project is to study the spectra and composition of the highest energy cosmic rays. The Argonne group is led by Spinka. Possible sources of cosmic rays range from galactic iron nuclei to extragalactic protons, photons, or neutrinos. Cosmic ray showers are observed in the Auger experiment with two independent detector systems: a surface array composed of water Cerenkov tanks

(live time  $\sim 100\%$ ) and a telescope array of fluorescence detectors (live time  $\sim 10\%$ ), similar to those in the Fly's Eye, HiRes, and Telescope Array experiments. Hybrid events detected with both systems allow, for the first time, cross checks of energy calibrations and tests for systematic effects resulting in a significant improvement of cosmic ray energy determination. For example, there is evidence for differences in energy calibrations in previous experiments that used different types of detectors. The southern Auger observatory is under construction near Malargue, Argentina, with completion expected in 2006. A northern Auger site in southeastern Colorado will be proposed in the next year in order to attain full sky coverage; this would provide important information about the origins of these cosmic rays.

The fluorescence detectors record shower development in the atmosphere. The total light yield is obtained after correction for atmospheric conditions and geometric effects. The relationship between total light yield and the shower energy relies on measurements with a few electron energies from many years ago and has an estimated uncertainty of  $\pm 15\%$ . The goal is to significantly improve the cosmic ray energy uncertainty associated with the fluorescence detectors in Auger and elsewhere. However, measurements at lower energies are required to reduce the overall cosmic ray energy uncertainty to  $\pm 5\%$ , because it is expected that approximately half the light yield results from energies below 10 MeV.

A series of tests and measurements are being performed with the AIRFLY apparatus, in collaboration with members of the High Energy Physics (HEP) division, using three unique facilities at Argonne: 1) the HEP Division's Argonne Wakefield Accelerator (AWA), 2) the Chemistry Division's Van de Graaff accelerator, and 3) the Advanced Photon Source. Unique energy scans, pressure scans, and spectra have been recorded and analyzed.

In addition to fluorescence measurements, Argonne is building prototypes for muon detectors to be added to the southern site. The detectors are using MINOS-type scintillator and multi-anode PMTs, therefore they build on Argonne experience. This effort is being funded by Argentina, who is developing the electronics. Three quarter-size prototypes have been shipped to Argentina for testing, and are performing well. The design of full-scale prototypes is underway. Muon detectors are important for two reasons: 1) determining the primary composition of cosmic rays, in particular separating protons from iron, which is crucial for understanding the origin of the cosmic rays; 2) identifying hadron showers from neutrino interactions, which is the best way to discover new particle physics in ultra high energy cosmic rays.

The initial planning for the Pierre Auger Observatory assumed detection of cosmic ray showers with angles up to  $60^\circ$  from the zenith. More recently, it has been realized that nearly horizontal showers will also be recorded. Neutrino interactions will produce showers with a significant number of electrons and positrons, even though they appear to have gone through the equivalent of several atmospheres of air. Thus, the Auger experiment is the highest energy neutrino detector. These neutrino interactions are the cleanest way to probe effects of TeV-scale gravity such as black holes at masses beyond that which can be probed at the LHC. They can also be used to probe any other new particle produced in neutrino interactions, with mass sensitivities approaching 100 TeV. The neutrino flux, however, from standard processes is expected to be  $\sim 5$  events/year. In order to improve the neutrino detection capability by  $\times 1000$  or more, we

are collaborating with Brookhaven on a novel radar detection scheme. Currently we are using the signals transmitted from TV stations 300 km away from Argonne, which are reflected off meteors and cosmic rays. This field is still in its infancy, but within two years a four antenna system would be placed at Auger South to calibrate its energy response.

## **Appendix 4: Outlines of additional possible initiatives**

In this section, we present outlines of future steps that could be taken for initiatives based on the nucleosynthesis, compact-object, and cosmic-ray themes discussed previously. These were omitted from the earlier sections to keep them brief.

### **An enhanced program in Nucleosynthesis/Cosmochemistry science might include:**

1. Hosting extended visits by established scientists, and/or holding workshops, with emphasis on the following areas: 1) galactic chemical evolution models and their relation to star surveys, 2) dust in the ISM and its relation to the presolar grains, 3) the measurement of cosmic ray compositions and their relation to source compositions. Given the strong programs in Physics and Materials Science, a general nucleosynthesis workshop might raise our profile.
2. Hire a staff theorist in the Physics Division specializing in hydrodynamical aspects of nuclear astrophysics. Maintain presence of a postdoc in HEP working on nuclear composition in TrICE. HEP could also seek a cosmic-ray composition experiment to join, and hire a staff member oriented toward that project.
3. Adding a student to the Atom Trap Trace Analysis group would give a boost to the Kr-isotope cosmochemistry effort.
4. Continued or increased investment in nuclear data for astrophysics would feed this program. Effort should be directed into finding cosmic-ray compositions in HEP, perhaps building on TrICE and/or finding and joining a collaboration to build a cosmic-ray composition experiment. Continued or increased investment in presolar grains in MSD would also feed this program. Again assuming that a place can be found at Argonne for an optical astronomer, and that the ATLAS telescope will have a spectrometer in relatively short order, Argonne could buy into this project and hire a staff astronomer interested in stellar compositions. HEP could also seek collaborators who are interested in producing a large-data-flow stellar spectroscopy survey on a dedicated instrument and apply their expertise there, much as other particle-physics groups have done with the MACHO, Sloan, and DES surveys.
5. The meeting opportunities that would best feed this program would probably be a simple expansion of the existing astrophysics seminars.

### **An enhanced program in Compact Object science might include:**

1. Hosting further workshops on 1) the nova problem, 2) X-ray bursts (maybe already too many such meetings), 3) pulsar physics with VERITAS, 4) nuclear data needs for compact-object studies, or 5) nova nucleosynthesis; or alternatively bringing in people working in these areas for extended collaboration visits.

2. Hire a postdoc in the physics division to pursue nuclear data needs for novae and X-ray bursts. Hire a staff or postdoc theorist in PHY who works in the area of compact objects. Hire a postdoc in MSD to carry out a dedicated search for clear nova signatures in the presolar grains. Hire a postdoc who will work on VERITAS and pursue compact-object science with it.
3. The work of the Flash Center at the University of Chicago and the associated visualization group in MCS division would help draw talent and provide resources. The Flash Center is definitely a source of collaborators for theoretical efforts or for coupled theory/experiment efforts to identify and address important sources of uncertainty. Northwestern University has some expertise in this area.
4. Possible experimental efforts are emphasis on nova grains in MSD, relevant nuclear data efforts in Physics experimental groups, and the pursuit of compact-object science at VERITAS. HEP could also seek to join a satellite X-ray astronomy project like Constellation-X and position itself to participate in the science done with the instrument.
5. Shift emphasis of astrophysics lunches to compact objects, or start a separate compact-object discussion group.

**An enhanced program in Cosmic Ray science might include:**

1. Workshops or visitors emphasizing some of the following areas: 1) cosmic ray composition and its evolution across the energy spectrum, 2) the role of cosmic rays in the Galaxy (energy balance, cosmic-ray nucleosynthesis, dust sputtering...).
2. It may be difficult to find theorists whose work centers on this area. Investment in VERITAS (and its next-generation successor) and personnel to work on it would continue at the present pace. More manpower could be invested in Auger, and perhaps in neutrino detection. Some members of the Physics Division could study unknowns in cosmic-ray propagation and nucleosynthesis (primarily at energies below  $10^{17}$  eV) and seek to remedy them with cross section measurements, perhaps bringing in a postdoc to work with the existing astrophysical cross sections group.
3. There is abundant opportunity for collaboration with the University of Chicago, with its long history of cosmic-ray research, and for using its proximity to draw people in. This is already happening with postdocs in HEP division and should be maintained and expanded.
4. Continue investment in Auger, VERITAS, and radar neutrino detection. Argonne could also seek a major role in a next-generation gamma-ray telescope. Direct some Physics Division effort toward cosmic-ray propagation and nucleosynthesis, building on existing experimental and theoretical effort in astrophysics. Perhaps effort in MSD could be directed toward extinct early-solar system radioactivities that may have been produced by cosmic rays. HEP could also seek next-generation cosmic-ray composition experiments to join.
5. Constitute a “cosmic ray working group” including all interested individuals to meet frequently and discuss cosmic ray physics. Emphasize this topic in selection of speakers at seminars across the divisions and at the astrophysics lunch seminars.

## Appendix 5: Overview of Future Experimental Projects

A wide range of possible new experimental projects have been investigated, but they are far from comprehensive. The projects investigated include experiments in dark energy, dark matter, cosmic rays, gamma-ray and x-ray detection, and neutrino detection.

1. The Fermilab-led Dark Energy Survey (DES) is a 500 megapixel CCD camera upgrade for the Blanco 4m telescope in Chile. A 3 degree<sup>2</sup> area will be sampled about once per minute. It will perform a ~5% measurement of the dark energy parameter  $w_0$ , using three techniques: 1) Type 1a supernovae as discussed in this report, 2) galaxy cluster counting versus mass and redshift, and 3) weak lensing of 300 million galaxies. DES is a \$22M project that if approved this year, claims to see first light in 2009. The collaboration includes members from UC and Illinois.
2. The Large Synoptic Survey Telescope (LSST) is a much more ambitious project than DES. It will measure  $w_0$  to ~1%, as well as the evolution of the dark energy equation of state. LSST is a \$270M project that claims to see first light in 2013 if funding starts in 2009. It recently received \$14M from the NSF for R&D. The site will be selected in April 2006. The camera is 5 gigapixels, x10 more than DES, producing 15 Terabytes of data per night. The collaboration includes UC, Illinois, SLAC, Brookhaven, Livermore. The large mechanical control issues seem well suited to an Argonne role, but this part of the telescope is being built by NSF institutions; the DOE labs are building the CCD camera.
3. The space-based dark energy program, called Joint Dark Energy Mission (JDEM), is expected to call for proposals in 2007. DOE has placed a cap of \$600M on this project. There are three competitors; 1) Supernova Acceleration Probe (SNAP) which is based at LBL, 2) Dark Energy Space Telescope (Destiny) led by Arizona State University, and 3) Joint Efficient Dark Energy Investigation (JEDI) led by the University of Oklahoma. SNAP has collaborators at FNAL and the University of Chicago.
4. The Super Cryogenic Dark Matter Search (SuperCDMS) is the official name for CDMSIII, a proposed upgrade of CDMSII. CDMSII is currently taking data in the Soudan mine and is the most sensitive direct detection dark matter experiment. The first phase of the upgrade would increase the amount of Germanium by x5 over the current detector. Steady improvement in sensitivity requires better shielding and a deeper location, probably requiring a move to SNOLAB. There are no Illinois universities involved.
5. The Chicagoland Observatory for Underground Particle Physics (COUPP) is a small collaboration between UC and Fermilab investigating the use of bubble chambers at very low superheat pressure (vapor pressure – operating pressure). Below 40 psi the detector is only sensitive to nuclear interactions, hence is a candidate for a very large dark matter experiment. It is currently funded with ~\$100K of discretionary funds from each institution.

6. A priority for the astrophysics community is the construction of a 30m telescope, much more sensitive than the current ~10m Keck and Magellan telescopes. These two groups have proposed technologies for the 30m telescope, at ~\$1B each. A third technology, which is further behind but may be ½ the cost, is being promoted by UC, Illinois, and Northwestern, consisting of a large array of small (~30cm) mirrors, each with fast adaptive control systems. Each group is submitting proposals to AURA for a \$14M R&D grant. Argonne is involved in this proposal as project managers and leader in the mechanical design.
7. A Detector of Neutrinos from Supernovae (ADONIS) is a detector concept that is designed to identify neutrinos from a galactic supernovae, which is expected about every 30 years. A supernova releases 99% of its energy in neutrinos, and in the near future there will not be a large neutrino detector to observe it. If detected, a wealth of neutrino and astrophysics becomes available. The detector is a combination of lead, gadolinium, and plastic scintillator sheets, with an approximate cost of \$50M. An important challenge is to identify a strong science program while waiting for the supernova. HEP and PHY personnel are involved in this detector concept.
8. In the last year workshops have been held in the U.S. for a next generation gamma-ray telescope, with a sensitivity x10 more than the HESS and VERITAS telescopes now taking data. It is expected to become an international effort in the near future, with an expected cost of ~\$100M. The VERITAS group in HEP is participating in this study, leading the advanced detectors working group.
9. The Pierre Auger Observatory was designed to have full-sky coverage, and with the southern half nearing completion this year the focus is turning towards the north. Last June the site was selected to be southeastern Colorado. Two workshops have been held in Colorado discussing the timing and content of R&D and full proposals. It is expected the full proposal (\$50-\$100M depending on proposed size) will be submitted in the next year. The Auger group in HEP is participating in these studies.
10. Constellation-X is a group of four space-based x-ray telescopes. In the 2000 NRC report, it was given 2<sup>nd</sup> priority after the James Webb Space Telescope. It will have a significant impact on measurements of dark energy and dark matter, supernova remnants, and accreting binary systems. It is a \$1B instrument, scheduled to launch in 2018. Northwestern is involved in the development of hard x-ray detectors for the telescopes, and is a member of the science team. Also on the science team is the Argonne lab director. Recent news reports question the funding for this project.

## Appendix 6: Generic Detector Development

The chances for long term success and growth of astrophysics at Argonne is enhanced by unique experimental facilities and technical expertise at the laboratory. Argonne is already using such capabilities for astrophysics, here are the highlights:

1. The RIMS is 10 times more sensitive than standard mass spectrometers and is being used to analyze samples from NASA's Genesis and Stardust experiments.
2. The ATLAS accelerator is being used for astrophysics cross section measurements with stable and radioactive beams.
3. ATTA will be used for trace analysis in cosmochemistry.
4. The fast electronics and photomultiplier expertise in HEP and the PBCS electronics group is being used for TRICE/VERITAS.
5. The AWA, APS, and Van de Graaff accelerators are being used for vital fluorescence calibrations for Auger and other experiments.
6. Expertise in project management and mechanical design is contributing to the proposal for the 30 meter telescope.

This is an impressive list, but fails to tell the complete story: 1) The vast majority of the astrophysics community is not aware of what Argonne has to offer; 2) Some Argonne facilities sit idle a good fraction of the time; and 3) With uncertain budgets and projects, many Argonne divisions struggle to maintain steady work for talented engineers and technicians.

There are many Argonne capabilities that are not being applied to astrophysics, here is a sample:

1. Expertise in Grid computing and database management could be useful for the next generation of high-rate astrophysics experiments.
2. Control systems design and development for experiments weighing hundreds of tons is not uncommon at Argonne. Such capabilities might be applied to the next generation of large telescopes.
3. The PBCS electronics group has experience in high resolution CCD imaging detectors, large area x-ray detectors, Ge and BGO detectors for gamma ray tracking, high resolution neutron detectors, and silicon detectors, fast and sophisticated trigger electronics.

These capabilities can be applied to new experiments related to the central scientific goals of this proposal, which is the traditional approach. In addition, it would be desirable to expand the Argonne detector horizons. This might be accomplished by short-term R&D projects, in association with scientists at local universities, that are not directly related to the central science goals of a new initiative. Some possibilities include the new projects discussed earlier: 1) Small mirror construction and fast feedback systems for the 30m telescope; 2) bubble chamber technology for dark matter; 3) high resolution gamma-ray cameras; 4) radar detection of air showers; and 5) hard x-ray detection for space-based telescopes. Expanding horizons could also include basic capabilities such as silicon chip development.

Short-term R&D projects in astrophysics detector development, outside the main scientific thrust of a new initiative, would be best served by an identified coordinator. This coordinator would become completely familiar with all of the relevant Argonne technical capabilities, advertise them, and remain apprised of new projects and technical needs in the astrophysics community. A new strategic initiative in astrophysics could

provide the seed for a half-time position for such a coordinator, becoming a permanent fixture if successful in bringing in new projects to Argonne.